A Short Ion Path High Voltage Tube

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A vacuum tube for the acceleration of charged particles is described. The total acceleration of the ions takes place in a distance of 18 inches although the total height of the tube is about 14 feet. It has been used at one million volts peak a.c. with target currents of 5 ma of electrons and 0.2 ma of positive ions.

BASED on the experience gained in the construction and operation of high voltage vacuum tubes in the W. K. Kellogg Radiation Laboratory,[1, 2] a short ion path tube was designed and built for further nuclear research. With our voltage supply it is difficult to adjust the voltages on the accelerating gaps and hence secure focusing as is done, for instance, with d.c. tubes by variable corona loss. It was accordingly thought that under conditions of poor focusing, more current could be delivered at the target with a shorter ion path.

The vacuum tube consists of four porcelain bushings[3] as shown in Fig. 1. The two lower bushings are 30 inches inside diameter and 39 inches high. The upper two are 15 inches inside diameter and 34 inches high. They are $1\frac{1}{2}$ to 2 inches thick and are corrugated on the outside. The outside surface is glazed but not the inside. This has not seemed to affect the vacuum attainable, but slightly hinders cleaning the inside. The external flashover voltages are 400 kv for the large bushings and 330 kv for the small ones. The bushings are separated by steel plates and the joints are made vacuum tight by several layers of ordinary electricians' rubber tape and shellac. The plates support the shields and are connected through protective 1 megohm water resistances to four 250 kv transformers which are cascaded to give one million volts r.m.s. Since these transformers are rated at 1000 kva no care needs to be taken to prevent corona.

The shields are made from $\frac{1}{16}$-inch cold rolled automobile body steel, rolled and welded into cylinders with $\frac{3}{4}$-inch pipe hoops welded on the ends. All the welds are carefully smoothed by hammering, grinding and using emery paper. The diameters of the cylinders are 3 inches, 8 inches, 12 inches, 19 inches and 26 inches, determined mostly by the inside diameters of the second and fourth bushings. Their lengths are 139 inches, 122 inches, 90 inches, 55 inches and 19 inches, so that each shield goes halfway up in the next higher bushing and serves to protect the walls of the bushings from puncture. So far no punctures have occurred. The shields are clamped

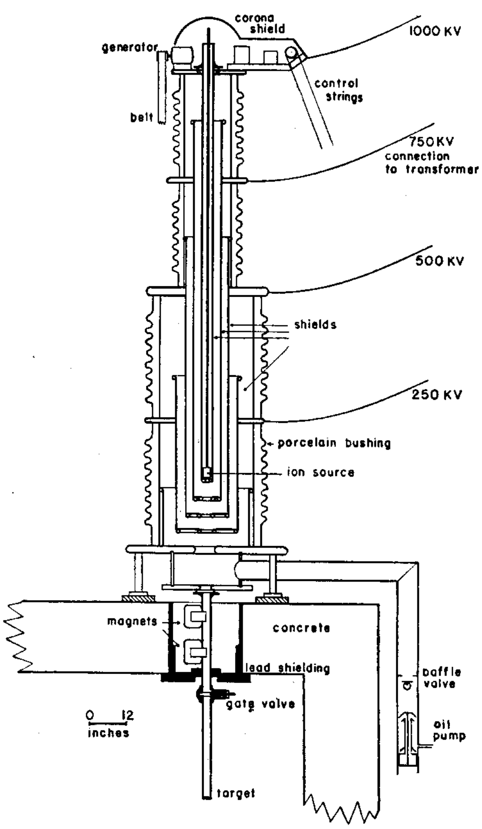

Fig. 1. Cross section of the tube.

[1] Crane and Lauritsen, Rev. Sci. Inst. **4**, 118 (1933).
[2] Crane, Lauritsen and Soltan, Phys. Rev. **45**, 507 (1934).
[3] These bushings were manufactured by General Electric Company and are of the type developed for switches on the Boulder Dam project.

by a frame held by leveling screws and centered carefully at their lower ends. In the bottom end of each shield is a focusing plate with a 3-inch hole through which the ions are accelerated. This divides the tube completely into four separate sections and at the same time makes the ion path short and the external separation long.

The field strengths at different places on the shields have been calculated roughly and amount to 50 or 100 kv per centimeter for the top two shields and less than half this for the lower shields when the total voltage is one million volts. This is less than is usually considered breakdown field for cold emission in a vacuum.[4] When voltage was put on each section separately, they all withstood voltage up to their external flashover value. However, the practical voltage limit is at present about one million volts total. With further careful outgassing and running at high voltages this limit may be increased. Due to the large area of metal exposed to electric fields in this tube, outgassing is quite important. Care has to be taken during outgassing not to allow arcing inside since this can easily result in melting the steel shields.

A tank is bolted onto the bottom of the tube and a 6-inch pumping lead is soldered onto it. This leads to three metal oil diffusion pumps (6 inches, 3 inches and $1\frac{1}{2}$ inches in diameter) in series backed by a Hypervac. These pumps are of the ordinary umbrella type and pump approximately 200 liters per second. In order to be able to check the pumps in case of leaks, the baffle just above the six-inch pump is replaced by a baffle valve, which can be closed by a cam operated through a water valve packing. Ordinary water valves, gate valves, etc., can be made quite vacuum tight if the packing is replaced by string smeared with stopcock grease and the screw joints painted with shellac. A Pirani gauge reads changes in pressure and a McLeod gauge gives the absolute pressure in the tube. The Pirani is made of several feet of 1 mil platinum wire in a 3-inch water-cooled brass can. With an ordinary wall galvanometer across a bridge circuit, it gives a deflection of 5 to 10 centimeters for a pressure change of $5\cdot10^{-5}$ to 10^{-4} mm of Hg. The zero drift which is due mostly to change in temperature of the cooling water and change in voltage of the dry cells is slow and can be checked on the McLeod.

The ion source used is similar to that described by Crane and Lauritsen.[2] The insulation is of Pyrex glass and lavite and the metal parts are brass. The ion source can be lifted out of the 3-inch electrode for replacing the filament. The power is supplied by a small 500-watt 500-cycle self-excited 110 volt generator run by a belt from the ground. The a.c. is transformed to give 5 amp., 10 volts a.c. for heating the filament, and transformed and rectified to give $\frac{1}{2}$ amp., 400 volts d.c. for the plate, and 5 ma, 1000 volts d.c. for the canal. The voltages are flashed in synchronism with the cloud chamber so that ions are accelerated only during the 1/10 of a second when the chamber is sensitive. Gas is let into the ion source through a needle valve at the rate of less than 1/20 of a liter per hour. The ion source supplies currents of 0.3 to 0.4 ma. of ions, of which about 0.1 to 0.2 ma of unresolved ions hit the target. The current to the target increases roughly linearly with the voltage on the canal and with the size of the canal. The maximum in the target current—filament current curve reported by Crane[5] is similarly observed.

The ion beam is quite broad and covers the 2-inch target fairly evenly. Two magnets with fields of 300 gauss are used to remove electrons from the beam. By making the fields opposing, the ion beam is not deflected, but only slightly displaced. The target tube is lined with aluminum to reduce the energy of the x-rays formed by the electrons. The observation room is well shielded by lead and concrete. A 2-inch, nonrising stem, wedge gate valve in the target tube allows the target to be replaced without losing the vacuum in the main tube. A rough magnetic analysis made with photographic film shows that about half the ions have energies within 90 percent of the peak energy. This is what would be expected since the transformer set produces a good sine wave voltage and the focusing varies with the voltage.

The peak voltage on the tube is read with a voltmeter connected to a special winding on the first transformer. This was calibrated up to 500 kv against a 50 centimeter sphere spark gap

[4] H. W. Anderson, Rev. Sci. Inst. **6**, 309 (1935).

[5] H. R. Crane, Phys. Rev. **52**, 11 (1937).

using the A.I.E.E. standard.[6] Above 500 kv the voltage-voltmeter reading curve was extrapolated linearly. The voltage-voltmeter reading curve was found to be linear up to 1000 kv by Sorenson, Hobson and Ramo who measured the voltage of the transformers with a sparkless sphere gap voltmeter using 100 cm spheres.[7]

[6] A.I.E.E. Standard No. 4 for sphere gap voltage calibrations, A.I.E.E. **55**, 783 (1936).
[7] Sorenson, Hobson and Ramo, A.I.E.E. **54**, 651 (1935). Sorenson and Ramo, A.I.E.E. **55**, 444 (1936).

This tube performs very much like the one of Crane and Lauritsen but can be run at a slightly higher voltage. Without magnetic analysis it is hard to make comparisons with other accelerating arrangements. It is, however, very useful for many nuclear problems and is being used in the investigation of neutron energies.

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Effects of Fringing Flux in Large Magnets

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In the construction of large magnets for cyclotrons account should be taken of the large amperian force of interaction between the current in the energizing coils and the fringing flux. This has not been mentioned in the literature due to the following reasons. First, the coils in most designs are placed flush against the shoulder of the yoke. Second, there is a common belief that a design which reduces the fringing flux to a small value will be free from any large scale interacting forces. This is far from being the case, and unless proper precautions are taken beforehand the installation may be damaged.

The Purdue cyclotron[1] was designed after a suggestion made by H. A. Bethe to secure as high a value for $H\rho$ as is possible. This is accomplished by using tapered pole pieces in place of the straight cylindrical ones. The tapered cylinder, following Bethe, is shaped according to the equation

$$r^2(y)=R^2\left(1+\frac{4}{\pi}\frac{d}{r}\log\frac{y}{d}\right)\Big/\left(1+\frac{4}{\pi}\frac{d}{r}\log\frac{a}{d}\right),$$

where $r(y)$ is the radius of the pole piece at a point y above the equatorial plane through the center of the gap, R is the radius of the pole piece at a distance a from the equatorial plane, $2d$ is the width of the gap and $2a$ is the distance between the yoke pieces at the point of attachment of the poles. In a straight cylinder the value of $H\rho$ in the gap is

$$H_0R\Big/\left(1+\frac{4}{\pi}\frac{d}{r}\log\frac{a}{d}\right)=\frac{H_0R}{b},$$

where H_0 is the field in the pole piece at a point farthest from the gap, while in the tapered cylinder it is $H_0R/(b)^{\frac{1}{2}}$.

The Purdue cyclotron was designed to produce 20 MV protons. It has tapered pole pieces of the above shape. This design has the advantage of allowing a considerable saving in the amount of iron and copper used in the cyclotron. With it a large field strength can be produced with a much smaller requirement of iron and copper and a smaller consumption of power than would be necessary for the same field from straight cylindrical or conical pole pieces. To reduce the fringing flux it is advisable to keep the energizing coils as near the pole gap as possible. On account of practical considerations of design this is not always possible, but we have kept the coils some distance away from the vertical and horizontal members of the yoke. The relative positions of the coils, poles and yoke can be seen in Fig. 1(A).

[1] Construction of the cyclotron was made possible in part by a grant to Purdue University from the Research Corporation, New York City.